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An Estimate of the R and D Costs to Develop the Noise Reduction Technology for the Design and Fabrication of Quiet Machines Typically Used by the Fabricated Metal Products Industry

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This is a task report of effort directed toward a pilot study on one noise intensive industry (Fabricated Metal Products) to more clearly define the machinery noise problem of that industry, the technology available to reduce the machine noise levels, the technology that needs to be developed and the most cost/effective/beneficial means of providing federal research, development and demonstration participation. Specifically, this task was directed toward estimating the R&D costs associated with developing the noise reduction technology to allow the quiet machinery, needed by this industry, to be designed and fabricated. This study concludes that 94 million dollars can be saved through a closely coordinated RD&D program over a loosely controlled program for developing and implementing quiet machinery technology typical of each machine type.

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Task Report J6131

by

E. P. Bergmann

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Project Officer

E. Berkau

U.S. Environmental Protection Agency
Industrial Environmental Research Lab
Cincinnati, Ohio 45268

Prepared for

Environmental Protection Agency
5555 River Avenue
Cincinnati, Ohio 45268

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ABSTRACT

This is a task report of effort directed toward a pilot study on one noise intensive industry (the Fabricated Metal Products Industry) to more clearly define the machinery noise problem of that industry, the technology available to reduce the machine noise levels, the technology that needs to be developed and the most cost/effective/beneficial means of providing federal research, development and demonstration participation. Specifically, this task was directed toward estimating the R&D costs associated with developing the noise reduction technology to allow the quiet machinery, needed by this industry, to be designed and fabricated.

This study compared the R&D costs of developing quiet machinery technology, for machines used in the Fabricated Metal Products Industry, on the basis of: 1) demonstration hardware typical of machines within a machine class; and 2) quiet machines typical of each machine type. A methodology of each alternative is presented and the costs estimated and compared. It is estimated that developing the demonstration hardware costs in the order of 23.9 million dollars. Conversely, developing the quiet machines for each machine type costs in the order of 117.3 million dollars. This study concludes that 94 million dollars can be saved through a closely coordinated R, D and D program over a loosely controlled program for developing and implementing quiet machinery technology typical of each machine type.

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SECTION I

CONCLUSIONS

This study compared the R&D costs of developing quiet machinery technology, for machines used in the Fabricated Metal Products Industry, on the basis of: 1) demonstration hardware typical of machines within a machine class; and 2) quiet machines typical of each machine type. A methodology of each alternative is presented and the costs estimated and compared. It is estimated that developing the demonstration hardware costs in the order of 23.3 million dollars. Conversely, developing the quiet machines for each machine type costs in the order of 117.5 million dollars. This study concludes that 94 million dollars can be saved through a closely coordinated R, D and D program over a loosely controlled program for developing and implementing quiet machinery technology typical of each machine type.

SECTION II

RECOMMENDATION

If the technology for quiet machinery for the Fabricated Metal Products industry is to be developed it is recommended that this be accomplished by the development of demonstration hardware typical of machines within a machine class.

SECTION III

INTRODUCTION AND SUMMARY

This is a task report of effort directed toward a pilot study on one noise intensive industry (The Fabricated Metal Products Industry) to more clearly define the machinery noise problem of that industry, the technology available to reduce the machine noise levels, the technology that needs to be developed and the most cost/effective/beneficial means of providing federal research, development and demonstration participation. Specifically, this task was directed toward estimating the R&D costs associated with developing the noise reduction technology to allow the quiet machinery, needed by this industry, to be designed and fabricated.

In order to provide a basis for estimating the R&D costs an approach had to be postulated as to how the R&D would be conducted. Two alternate approaches are presented and compared. The first approach considers the development of quiet components and assemblies. The assemblies are then integrated into quiet machines typical of machines in each of the 31 machine classes within the industry. This approach is characteristic of a federally funded R, D and D program.

The second approach considers the development of machines typical of each of the 160 machine types within the industry. This approach is more characteristic of an industry's approach to the problem. Both approaches are developed from a common phase which structures the problem.

A summary of the R&D costs are given in Table 1.

Table 1. R&D Cost Summary

Phase I - Structuring the Program Cost = 4.75 million dollars	
Phase IIA - Technology Development	Phase IIB - Technology Development
Demonstration Hardware	Quiet Machine Types
Cost = 18.73 million dollars	Cost = 112.79 million dollars
Total = 23.5 million dollars	Total = 117.5 million dollars

If Phase II costs are compared - since this phase relates to the development of the technology - it is seen that the technology demonstration program (Phase IIA) costs about 18.7 million dollars to develop 31 demonstration machines. The average R&D cost is $603,000/machine. The quiet machine development option (Phase IIB) costs about 112.8 million dollars to develop 160 quiet machines. The average R&D cost of this option is $705,000/machine.

SECTION IV

METHODOLOGY

The methodology chosen to estimate the R&D costs to quiet the machines used by the fabricated metal products industry consists of: 1) postulating an approach as to how the R&D will be conducted, and 2) estimating the cost of each element of the approach.

Two general approaches were considered and are presented. One assumes that a closely coordinated R&D program can be conducted which leads to demonstration hardware. The technology established under this program can then be applied by industry for noise reduction treatments for particular machine types. The second approach considers a more loosely coordinated program - such as could be conducted by the industry - in which machine types are treated. The noise reduction technology established for each machine type would then be available to each manufacturer of that type.

Figure 1 illustrates the procedural flow diagram which shows the organization of the major task elements of a noise reduction R&D program. This program is divided into two phases; Phase I is the structure of the problem, and Phase II is the development of the technology. Phase II considers the two alternative approaches, both of which draw from a common data base.

The terminology of the hierarchy of machines, as used in this report, is as follows: 1) machine group (e.g. metal cutting machines), 2) machine class (e.g. turning machines), 3) machine type (e.g. lather), 4) assemblies (e.g. drives), and 5) machine elements (e.g. pumps).

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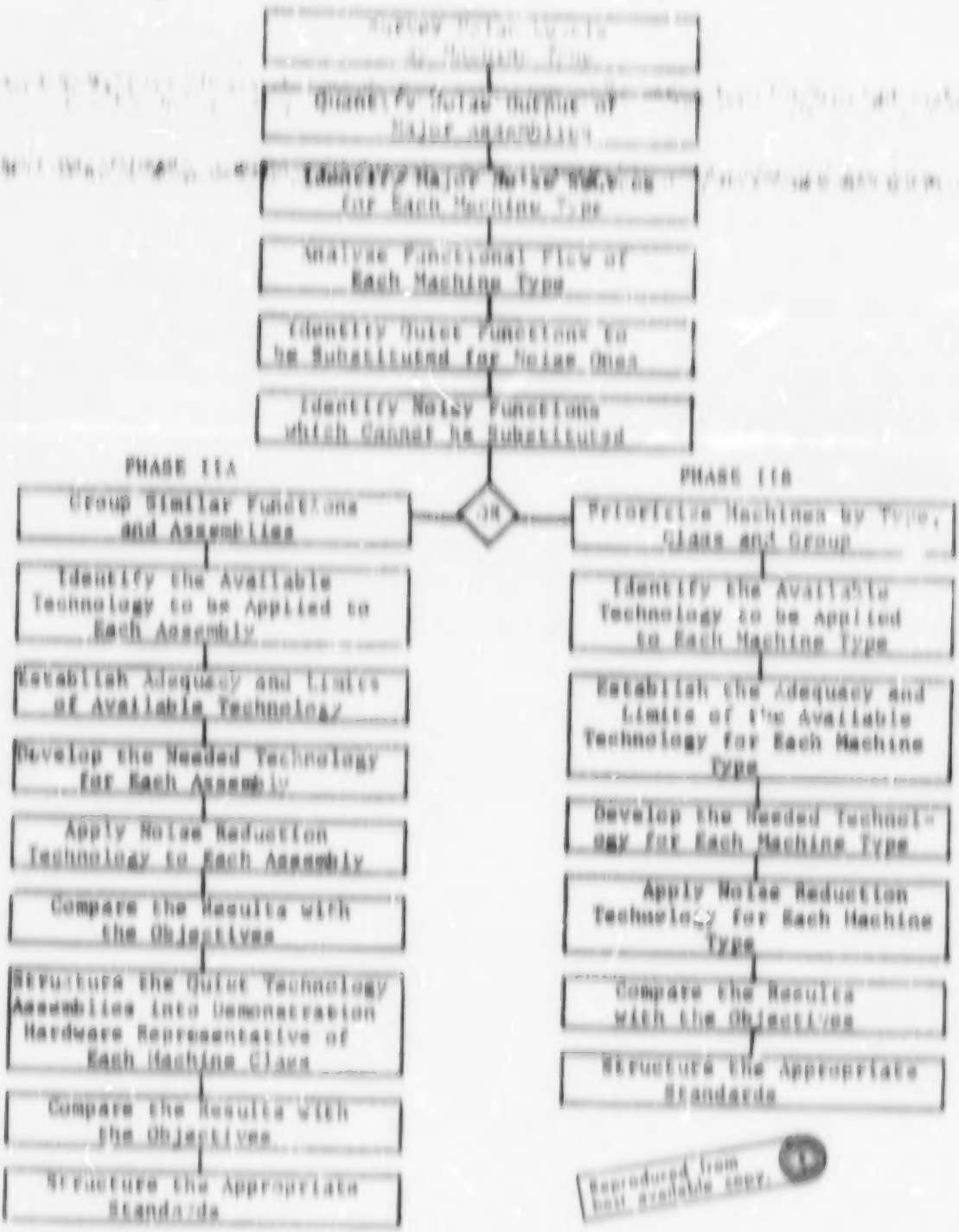
Survey Total Inputs for Machine Type
Quantify Noise Output of Major Assemblies
Identify Major Noise Sources for Each Machine Type
Analyse Functional Flow of Each Machine Type
Identify Quiet Functions to be Substituted for Noise Ones
Identify Noisy Functions which Cannot be Substituted
PHASE IIA
Group Similar Functions and Assemblies
Identify the Available Technology to be Applied to Each Assembly
Establish Adequacy and Limits of Available Technology
Develop the Needed Technology for Each Assembly
Apply Noise Reduction Technology to Each Assembly
Compare the Results with the Objectives
Structure the Quiet Technology Assemblies into Demonstration Hardware Representative of Each Machine Class
Compare the Results With the Objectives
Structure the Appropriate Standards
OR
PHASE IIB
Prioritize Machines by Type, Class and Group
Identify the Available Technology to be Applied to Each Machine Type
Establish the Adequacy and Limits of the Available Technology for Each Machine Type
Develop the Needed Technology for Each Machine Type
Apply Noise Reduction Technology for Each Machine Type
Compare the Results with the Objectives
Structure the Appropriate Standards
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Figure 1. Noise Reduction R&D Procedural Flow Diagram

PHASE I - STRUCTURE THE PROBLEM

The purpose of this phase are to provide the basic data on the noise levels and noise spectra of machines and major assemblies, to identify the major noise sources, and to organize the information. Phase I is composed of the following elements:

- Survey Noise Levels by Machine Type. The current data base of machinery noise information is incomplete and somewhat dated (References 1 and 2). A complete survey of machine noise levels (dBA) is needed.

- Quantify Noise Output of Major Assemblies. In order to isolate noise sources the noise output of the major assemblies should be quantified (dBA and frequency).

- Identify Major Noise Sources for Each Machine Type. The major assemblies of the 160 machine types should be segregated by noise levels.

- Analyze the Functional Flow of Each Machine Type. Process substitution can be a viable noise reduction alternative when selecting machine types. This same type of substitution can be investigated in terms of machine functions whereby quiet functions are substituted for noisy ones. In order to provide a basis for assessment, the functional flow of each machine type should be identified and analyzed in terms of noise level and substitution potential. It is also desirable to force a more fundamental investigation of machine functions to unlock the design approach from its rigor of tradition.

- Identify Quiet Functions which can be substituted for Noisy Ones. Some functions, such as orbital forging, squeeze casting and squeeze riveting, have the potential of being substituted for their more noisy counterparts. These functions should be identified to allow the broadest possible application over a range of machine types.

- Identify Noisy Functions which Cannot be Substituted. Some functions, such as grinding, are noisy, essential to a particular fabrication process, and cannot be readily substituted. These functions should be identified as areas requiring intensive application of research in order to achieve noise level commitments.

PHASE IIA - DEVELOP THE TECHNOLOGY VIA ASSEMBLY NOISE REDUCTION

This phase of the R&D program defines tasks which develop noise reduction technology for typical major assemblies. The quiet assemblies are then combined to form demonstration machines typical of each machine class. This methodology allows the broad application of the technology developed; but it also requires that each machine manufacturer develop the particular noise reduction technology peculiar to his needs. This phase has the following elements:

- Group Similar Functions and Major Assemblies on the basis that things that have similar functions also have similar problems.

- Identify the Available Technology to be Applied to Each Assembly. Within the framework of a recent study (Reference 2) 22 noise treatments were identified and distributed over 20 major assemblies. Sixteen of the assemblies did not have any noise treatments indicated. This implies that the available noise reduction technology is not evenly distributed over the assemblies.

- Establish the Adequacy and Limits of Available Technology to provide a basis for not developing existing technology.

- Develop the Needed Technology for Each Assembly by analysing the functional flow of each assembly and developing quiet machine elements.

- Apply the Noise Reduction Technology to Each Assembly. The quiet machine elements are combined into quiet assemblies. Some commonality of the developed technology should allow the use of quiet machine elements over a range of assemblies.

- Compare the Results with the Objectives and modify the noise reduction treatments as needed to achieve the desired level of noise control.

- Structure the Quiet Technology Assemblies into Demonstration Hardware Representative of Each Machine Class. This task will require that 11 quiet machines be built to demonstrate the availability and effectiveness of the noise control technology. The 11 machines will be representative of typical machines in each of the machine classes.

- Compare the Results with the Objectives and modify the noise treatments as needed to achieve the desired level of noise control and usefulness of the demonstration technology.
- Structure the Appropriate Standards based on the demonstration availability of noise reduction technology.

PHASE IIB - DEVELOP THE TECHNOLOGY VIA MACHINE TYPE NOISE REDUCTION

This phase of the program illustrates tasks related to developing the noise reduction technology relative to each machine type. This type of program is more typical of an industry's approach to the noise control problem - if the industry effort could be organized to allow a free flow of technical information. If this information flow is not attainable the amount of R&D effort required to support the random programs can be expected to be an order of magnitude higher. Phase IIB has the following program elements:

- Prioritize Machines by Type Class and Group by considering machine noise levels, numbers of machines and numbers of machine operators.
- Identify the Available Technology to be Applied to Each Machine Type. As with the technology identification of the major assemblies the technology as applied to machine types appears to be unevenly distributed over the 160 machine types (See Reference 2). However, availability, overlaps and gaps should be identified.
- Develop the Needed Technology for Each Machine Type by considering the applicable assemblies, the functions of the machine elements and the interactions of the elements and assemblies within the functional requirements of the machine type.
- Apply Noise Reduction Technology to Each Machine Type. One hundred sixty (160) quiet machines will be developed - each representative of a typical machine within its type classification.
- Compare the Results with the Objectives and modify the noise reduction treatments as needed to achieve the desired level of noise control.

- Restructure the Appropriate Standards based on the demonstrated technology.

SECTION V

PHASE I - COST ESTIMATE

TASK 1: COST OF SURVEY OF NOISE LEVELS BY MACHINE TYPE

There are 3,720,784 machines in the Fabricated Metal Products Industry, in over 27,000 companies, distributed over 160 machine types (Reference 1). Further, the machines are of various ages and levels of maintenance and repair. A noise survey of every machine in the industry would cost about 560 million dollars (at $150 per machine surveyed). A more tractable approach would be to survey a sample of noise levels of each machine type. This would reduce the survey size to 160 times the sample size.

It is recognized that the level of maintenance applied to the machine, as well as the normal wear, affects the noise level of the machine. In order to isolate these effects - which should be considered in a separate study - the survey should concentrate on machines which are less than two years old. Also the survey should be taken while the machines are in their normal production oriented mode of operation since this mode loads the machine to produce the characteristic noise which is to be reduced.

Based on these considerations the cost of the survey is estimated as follows:

- There are 160 machine types.
- Survey 20 samples for each machine type.
- Allot $150 per machine surveyed.

Cost = (160)(20)(100) = $480,000

TASK 2, COST OF QUANTIFYING THE NOISE OUTPUT OF MAJOR ASSEMBLIES

The noise output of each major assembly and the metal working process is to be quantified in terms of noise level and frequency. The study of the noise treatments (Reference 2) indicated that the average number of major assemblies for each machine class was seven (some machines have more and some less). When the metal working process is added it is evident that an average of eight noise spectral recordings (not necessarily readings) must be made for each machine type. The cost estimate for this task is then:

- There are 160 machine types.
- Survey 20 samples for each machine type.
- Record noise spectra for eight assemblies and processes for each survey site.
- Allot $80 for each noise spectra recorded.

Cost = (160)(20)(8)($80) = $2,048,000

TASK 3, COST TO IDENTIFY MAJOR NOISE SOURCES FOR EACH MACHINE TYPE

This task related to reducing and organising the data gathered in Tasks 1 and 2. Data will be gathered on 160 machine types, 20 samples per machine and 8 spectral recordings to be screened, categorised and compiled. At a rate of one per hour 13 man years of effort is required to perform this task. At a cost of $60,000 per man year (billed out with all overhead and salary related costs included) the cost for this task is $780,000.

TASK 4, COST TO ANALYZE FUNCTIONAL FLOW OF EACH MACHINE

There are 1,120 functional flow diagrams to be generated (160 machine types x 7 assemblies per machine type) and analysed. If 32 man hours of effort is allotted to each diagram the total effort required would be about 18 man years of effort. At a cost of $60,000 per man year $1,080,000 would be required for this task.

TASK 5, COST TO IDENTIFY QUIET FUNCTIONS TO BE SUBSTITUTED FOR NOISY ONES

The distribution of effort for this task is estimated as follows:

- There are 1120 functional flow diagrams.
- It is estimated that eight man hours per diagram will be required to identify noisy and quiet functions.
- About 1200 man hours will be required to group similar functions.
- Approximately 1680 man hours will be needed to identify potential substitutions.
- The total effort for this task is then 11,840 man hours or 6 man years.

At a rate of $60,000 per man year the cost of this task is estimated at $360,000.

TASK 6, COST TO IDENTIFY NOISY FUNCTIONS WHICH CANNOT BE SUBSTITUTED

It is estimated that the identification of noisy functions which cannot be substituted will require one man year of effort. At a rate of $60,000 per man year the cost of this task is estimated at $60,000.

SUMMARY OF THE COSTS FOR PHASE I

The costs for each task and for Phase I are summarized in Table 2.

Table 2. Summary of Phase I Costs

Task	Cost
Survey Noise Levels by Machine Type	$480,000
Quantify Noise Output of Major Assemblies	3,048,000
Identify Major Noise Sources for Each Machine Type	780,000

Analyze Functional Flow of Each Machine Type	1,080,000
Identify Quiet Functions to be Substituted for Noisy Ones	360,000
Identify Noisy Functions which cannot be Substituted	60,000
TOTAL	14,748,000

A review of Table 3 and the costs of each task indicates that about 66 percent of the costs of Phase I are allotted to tasks 2 and 4. These costs are primarily driven by: the 25,600 spectral surveys and their analysis; and the generation and analysis of 1120 functional flow diagrams. Cost reduction could be achieved by: 1) reduction in the sample size - this would also lead to some reduction in the ability to interpret the data; 2) a finding that many of the functional flow diagrams can be grouped into generic sets; and/or 3) extensive computerized data processing to reduce, segregate and compile the data.

SECTION VI

PHASE IIA - COST ESTIMATE

TASK 1, COST TO GROUP SIMILAR FUNCTIONS AND MAJOR ASSEMBLIES

There are approximately 20 major assemblies which must be identified and subdivided into functions, or machine elements. It can be expected that these elements can, in turn, be grouped by similar functions. Later, when noise treatments are applied to the machine elements some commonality can be expected to be effected when the elements are recombined into noise reduction treatments of the major assemblies. The cost for this task is estimated as follows:

- There are approximately 20 major assemblies.
- On an average it is assumed that there are five functional or machine elements per assembly. This results in 100 functional elements which must be identified and grouped.
- The effort for this task is estimated a two man months or 1/6 man year.

At a rate of $60,000 per man year the cost for this task is estimated at $10,000.

TASK 2, COST TO IDENTIFY THE AVAILABLE TECHNOLOGY TO BE APPLIED TO EACH ASSEMBLY

Some of the available technology has been identified in Reference 2. This information can be updated at the time of the task. It is estimated that 4 man months (1/3 man year) of effort will be required for this task. Based on this effort and a rate of $60,000 per man year the cost of this task is estimated at $20,000.

TASK 3, COST TO ESTABLISH THE ADEQUACY AND LIMITS OF THE AVAILABLE TECHNOLOGY

It is estimated that 4 man months (1/3 man year) of effort will be required to evaluate the adequacy and limitations of the available technology. At a labor rate of $60,000 per man year the cost for this task is estimated at $20,000.

TASK 4, COST TO DEVELOP THE NEEDED TECHNOLOGY FOR EACH ASSEMBLY

The cost of this task is estimated on the following basis:

- There are approximately 20 major assemblies with about five machine elements per assembly. This results in about 100 quiet machine elements to be developed.
- It is estimated that 1/2 man year of effort will be required for each element.
- It is estimated that 25 percent of the elements have duplicate technology.
- The labor cost is thereby estimated as: (100 elements) (1/2 man year/element)(.75)($60,000/man year) = $1,250,000.
- It is estimated that a hardware factor of 50 percent can be applied - that is the cost of designing and fabricating the hardware for the development effort will be 50 percent of the engineering effort.

The total cost of this task is estimated at $2,250,000 + $1,125,000 or $3,375,000.

TASK 5, COST TO APPLY THE NOISE REDUCTION TECHNOLOGY TO EACH ASSEMBLY

The quiet machine elements developed in Task 4 must be combined into the 20 major assemblies to demonstrate the assembly noise technology. It is estimated that 1-1/2 man years of effort will be required for the development of a typical quiet assembly. It is also estimated that a hardware

factor of 50 percent will be required for this task. At a labor rate of $60,000 per man year the cost for this task is estimated at $2,700,000.

TASK 6, COST TO COMPARE THE RESULTS WITH THE OBJECTIVES

Those major assemblies for which the noise reduction technology which was applied does not result in the required level of noise reduction will require additional development effort. It is estimated that this effort will be in the order of 10 percent of the original effort (the cost of Task 5). The cost of this task, therefore, is estimated at $270,000.

TASK 7, COST TO STRUCTURE THE QUIET TECHNOLOGY ASSEMBLIES INTO DEMONSTRATION HARDWARE REPRESENTATIVE OF EACH MACHINE GROUP

There are 31 machine groups. A machine type typical of the machines in each group is selected and a quiet technology demonstration machine is developed. It is estimated that three man years of engineering effort will be required to develop each of the 31 machines. It is also estimated that a hardware factor of 100 percent will be required for this task. The cost of this task is estimated at $11,160,000.

TASK 8, COST TO COMPARE THE RESULTS WITH THE OBJECTIVES

As with Task 6 it is estimated that the additional development effort needed to bring each machine's noise level down to that level required is 10 percent of the original effort. The cost of this task is estimated at $1,116,000.

TASK 9, COST TO STRUCTURE THE APPROPRIATE STANDARDS

It is estimated that one man year of effort at a rate of $60,000 per man year will be required to structure the appropriate noise standards for the industry. The cost of this task is estimated at $60,000.

SUMMARY OF THE COSTS FOR PHASE IIA

The costs for each task and for Phase IIA are summarized in Table 3.

Table 3. Summary of Phase IIA Costs

Task	Cost
Group Similar Functions and Major Assemblies	$ 10,000
Identify Available Technology for Each Assembly	20,000
Establish Adequacy and Limits of Available Technology	20,000
Develop the Needed Technology for each Assembly	3,375,000
Apply Noise Reduction Technology for Each Assembly	2,700,000
Compare the Results with the Objectives	270,000
Structure Quiet Assemblies into Quiet Machines	1',160,000
Compare the Results with the Objectives	1,116,000
Structure the Appropriate Standards	60,000
TOTAL	$18,731,000

The primary costs of this phase result from the development of the noise reduction technology. Development of quiet machine elements represents 18 percent of the effort; quiet assembly technology represents 16 percent of the effort; and quiet machine technology represents 65 percent of the effort. As with Phase I, Phase IIA costs are driven by numbers - 100 machine elements, 20 major assemblies and 3i machine groups.

SECTION VII

PHASE IIB - COST ESTIMATE

TASK 1, COST TO PRIORITIZE MACHINES BY TYPE, CLASS AND GROUP

There are 160 machine types, 31 machine classes and 5 machine groups. It is estimated that two man months of effort will be required to conduct this task. At a rate of $60,000 per man year the estimated cost of this task is $10,000.

TASK 2, COST TO IDENTIFY THE AVAILABLE TECHNOLOGY TO BE APPLIED TO EACH MACHINE TYPE

Some of the available technology has been identified in Reference 2. This information can be updated at the time of this task. It is estimated that four man months of effort will be required. At a rate of $60,000 per man year this task is estimated to cost $20,000.

TASK 3, COST TO ESTABLISH THE ADEQUACY AND LIMITATIONS OF THE AVAILABLE TECHNOLOGY

It is estimated that four man months of effort, at a labor rate of $60,000 per man year will be required to evaluate the adequacy and limitations of the available technology. The related cost is estimated at $20,000.

TASK 4, COST TO DEVELOP THE NEEDED TECHNOLOGY FOR EACH MACHINE TYPE

There are 160 machine types, an average of seven major assemblies for each machine type and an average of five machine elements per assembly. Since each machine type is being investigated explicitly it is estimated that an average of only three of the major assemblies will be identified as significantly noise sources on any machine type. This reduces the number of machine elements which must be treated to 2400 (160 x 3 x 5). Further, it appears reasonable to expect that in the order of 25 percent of the effort should be duplicable by even a rudimentary coordination effort. This reduces the number of machine elements to be treated to 1800 (.75 x 2400).

It is estimated that 1/2 man year of effort will be required to develop the technology for each element. It is also estimated that the hardware factor for this task is 50 percent. At a labor rate of $60,000 per man year the cost of this task is estimated at $81,000,000 (1800 x .5 x 1.5 x 60,000).

TASK 5, COST TO APPLY NOISE REDUCTION TECHNOLOGY TO EACH MACHINE TYPE

The quiet machine elements and assemblies developed in Task 4 are combined into the 160 machine types. It is estimated that: 1-1/2 man years of effort will be required to develop each machine type (average); the labor rate is $60,000 per man year; and the hardware factor is one. The estimated cost for this task is, then, $28,800,000 (160 x 1-1/2 x 2 x 60,000).

TASK 6, COST TO COMPARE THE RESULTS WITH THE OBJECTIVES

It is estimated that the additional development effort needed to bring each machine's noise level down to the level required is 10 percent of the original effort. The cost of this task is estimated at $2,880,000.

TASK 7, COST TO STRUCTURE THE APPROPRIATE STANDARDS

It is estimated that one man year of effort at a rate of $60,000 per man year will be required to structure the appropriate noise standards for the industry. The cost of this task is estimated at $60,000.

SUMMARY OF THE COSTS FOR PHASE IIB

The costs for each task and for Phase IIB are summarized in Table 4.

Table 4. Summary of Phase IIB Costs

Task	Cost
Prioritize Machines by Type, Class and Group	$ 10,000
Identify Available Technology for Each Machine Type	20,000
Establish the Adequacy and Limitations of Available Technology	20,000
Develop the Needed Technology for Each Machine Type	$1,000,000
Apply Noise Reduction Technology to Each Machine Type	28,800,000
Compare the Results with the Objectives	2,880,000
Structure the Appropriate Standards	60,000
TOTAL	$112,790,000

As with Phase IIA the major cost of the phase relates to developing the needed technology (72 percent of the effort), and assembling this technology into 160 quiet machine types (28 percent of the effort).

SECTION VIII

REFERENCES

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